DESIGN AND FABRICATION OF A TELEOPERATED TRACKED VEHICLE

by

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by
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CERTIFICATE

It is certified that the work contained in the thesis entitled **"Design and Fabrication of a Teleoperated Tracked Vehicle"** by **"Capt. M.S. Sunderam"** has been carried out under our supervision and that this work has not been submitted elsewhere for a degree.

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ABSTRACT

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This project aims at a development of a Model of a Teleoperated Tracked Vehicle for increased mobility in rugged and marshy terrain. The tracked vehicle is also capable of negotiating nominal gradients and obstacles. The teleoperation is achieved with Joy stick control, by means of a set of wires for line of communication with the tracked vehicle.

DEDICATED

TO MY

WIFE

AND DAUGHTER

VEENA

ACKNOWLEDGMENT

I hereby wish to extend my sincere gratitude to my supervisors for having permitted me to work in an environment of complete freedom and utmost co-operation. The working model would not have been conceived without the enthusiastic co-operation of Manufacturing Science Lab personnel, particularly Mr. R. M. Jha, Mr. Bharthia, Mr. Sharma and Mr. Prem Prakash. I wish to records my thanks to Mr. Sudhir Srivastava and Mr. Vivek Shukla of Stress Analysis Lab. and Robotics Centre for Assisting me in presenting this document.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

We have known of the longbow, use of gun powder, steam driven vessels, rapid fire machine guns, the tank, Airplanes, Nuclear weapons, Missiles. These inventions are merely a few of the military technologies that have changed warfare, shaken empires, rearranged societies, changed the social structures. Today we live in a world where many fear that nuclear and chemical weapons threaten the very existence of mankind. The efficiency of using robotic vehicles is no longer in question. The debate in now focused on the question as to what extent men should be "In The Loop" in their command and control. Technologists are developing artificial intelligence hardware, software architectures and sensor technologies to allow for the fielding of autonomous vehicles by the turn of the century. To appease these concerns, many of the weapons laboratories are emphasizing the development of teleoperators that maintain the man in the loop.

Remote controlled vehicles are those in which the operator relies on either his own line-of-sight vision from a distance or sensor data to maneuver a vehicle to perform a certain mission. There have been several interesting proposals for using teleoperated robots in the battle field [1].

Teleoperators do not replace people but allow them to do in safety job which would otherwise be dangerous or impossible. If their use has an aspect which is cause for concern it is that teleoperators make it easier to develop and manufacture nuclear,

chemical and biological weapons.

Modern teleoperators originated with the need to handle radioactive material. When it became necessary to separate the material from its handler by a shielding wall, mechanism had to be developed to transmit an operator's hand movements to a grasping device on the other side of a barrier [2].

Teleoperation and hybrid versions with some preprogramming capability have already been in widespread use by the military and police in dealing with terrorist devices and bombs. Britain led this development in building vehicles that could remotely deal with bombs set by the Irish Republican Army and Protestant Extremist Organization. The "Wheelbarrow" is the most popular explosive ordnance disposal robot in use throughout the world. It is fitted with a TV monitor, a shot gun for explosive detonation, various booms and mechanism and tow ropes and cable. It was developed in a joint effort by the UK Military Vehicles Experimental Establishment and the Royal Ordnance Corporations, Morfax Ltd. received the license to make the machine and has sold some 500 Wheelbarrows to military and police organization in some forty countries.

1.2 PREVIOUS WORK DONE [9, 10]

Edwin Johnsen was the first to have advocated the theory of teleoperation in 1967. This led to the development of robotics in general followed by teleoperation. The state of art of mobile robots came mainly from the americans. The American Robot Association knows of over two hundred individual robot designers who have made their own mobile robots. They large from Shakey, one of the first mobiles designed by the stanford Research Institute. The main initiative in UK comes from British Petroleum Ltd. who are running the world's largest robot building competition. Apart from very few companies the trend is principally aimed to cater for the educational market. To illustrate a mobile educational robot would be Hero's commercial success. The advanced teleoperation include feed forward controls and feed back information for remote work in an environment requiring mobility, with human intervention at all levels. Computer science has already been used in teleoperation but only with respect to servocontrol. In achieving automatic tracking of television cameras to the area of operation, computer aided teleoperation for mobile vehicles becomes a reality, because the computer aids the human operator and can replace him in some tasks.

For the mobile vehicles restricted to land surface, the means of locomotion for robots are wheels, tracks, legs and air cushions [2]. The wheeled vehicles are the simplest method of locomotion, wheels are abandoned only when there is a pressing reason, namely if the terrain is marshy and having obstacles size

greater than wheel diameter. Tracks are intended for mobility on soft ground. Legged mobile robots are at their early stage of development. Legs having several advantages over wheels and tracks, however they are much more complicated and slow.

1.2.1 TELEOPERATED MOBILE PLATFORM

Some of the significant contribution towards mobile system are listed below [4] :

(i) **SHAKEY**- As brought out earlier this was an effort in mobile robot system and attempted by the stanford Research Institute. It consisted of two free wheels and two independent driven wheels propelled by stepping motors, a vidicon camera and an optical range finder alongwith several touch sensors. All elements were controlled by a single remote computer which was radio linked to the onboard instrumentation.

(ii) **JASON** - This was developed by the university of Berkeley between 1970 and 1975. This had a front free wheel and two rear wheels driven by DC motors with Ultrasonic range finders. A computer was connected to an onboard processor.

(iii) JPL **"ROVER"** and the **CMU "ROVER"** developed in the early 70's by the Jet propulsion laboratory and Carnegie Mellon University respectively. They were similar to "Jason" mentioned above, with CMU "ROVER" being more autonomous and intelligent. "SCOUT", "WHEELBARROW" and "HOBO" are few other mobile remote controlled robots used for anti terrorist activities.

1.2.2 TELEOPERATED VEHICLES IN DEFENCE

Various defence organizations have developed teleoperated tracked and wheeled vehicles the world over [1]. Some of the significant developments are briefly described below :

(i) TROIKA : Robert Fin Kelstein, president of Robotic Technology Inc., has proposed a concept of Troika, Which is a Russian term meaning three closely related things. Troika has three elements : a manned tank, an unmanned tank, and a low cost unrecoverable rocked propelled mini air vehicle (RPV). The unmanned tank provides defensive-action mission and escort to the manned tank. While the RPV would be launched from the manned tank to furnish advance warning of enemy tanks and anti-tank weaponry. The advantage of Troika is that it allows a tank crew to command the fire power and mobility of two tanks and also have some aerial reconnaissance support.

(ii) HUNTER AND HADRIAN : In light of Wheelbarrow's success, explosive ordnance disposal (EOD) robots are being manufactured by a number of other companies. Two other british-built robots, the Hunter, made by SAS group of Beacons field and the Hadrian built by Monitor Engineers of Wallsend, were present at the 1984 Olympic games at Los Angeles, for stand by use in coping with any terrorist devices. The Hunter is a radio-controlled vehicle that has a unique TRAVAD auxiliary drive system that quickly allows for the option of using tracks for surmounting obstacles, or wheels for greater speed on paved surfaces.

Besides bomb disposal, the Hadrian robot is also used for

mobile surveillance in prisons and in other areas, and in hazardous waste area. It has six drive wheels that allow it to climb and descend stairs, curves and steep embankments at a speeds upto 5 KPH. The Hadrian can place and detonate explosive via two separate, secure firing circuits, which are controlled from command console. It can also carry a five shot semi-automatic shot gun to disable the bomb's fire mechanism or clockwork.

The teleoperated vehicle developed at the Centre for Robotics, IIT, Kanpur, consists of three driven wheels mounted on a shaft coupled to two stepping motors. The two motors were used to control the motion of the vehicle. The position of the vehicle is represented and monitored on a (r,θ) coordinate system where one motor controls 'r' i.e.the radial movement while the other motor controls θ, i.e. the angular direction of the wheel shaft [3].

Further development by increasing the versatility of the earlier model of the vehicle was undertaken [4]. The changes in mechanical design of the system resulted in improvement of the efficiency and stability while removing the difficulty of entanglement of cable used for communication. The vehicle was fitted with a manipulator (SIR 1) and interfaced with PC-AT through RS-232 serial interface.

1.3 OBJECTIVE OF THE PRESENT WORK

The main objective of the present work is to design and fabricate a remotely operated tracked vehicle with a self contained power pack. Although wheeled vehicles operate smoothly over a level and hard surfaces, they are quite inefficient, in very soft soil and in rugged land where there are projections and depressions greater than the diameter of the wheel. Tracked wheels offer greater ability to cross natural terrain but cannot move side ways. This vehicle when boosted with adequate traction power could negotiate steep gradients and stairs with a good amount of payload. With the available manipulators mounted on this vehicle varied tasks could be achieved.

1.4 SCOPE OF THE PRESENT WORK

The remotely teleoperated vehicle designed, undertakes motions on rugged, but relatively plain terrain. As the tracks are made of Delrin (polymer) material it is restricted to be used in cemented or plain surfaces. However, the vehicle is capable of negotiating gradients upto 20° uphill. Steering is achieved by increasing the thrust on one track and reducing that on the other. Even the vehicle can be made to spin on a point, on the line of their driven axis by driving the left and right motors in opposite direction.

The mobilization of the vehicle is remotely controlled by a "Joy Stick" having two degrees of freedom. The Joy Stick basically generates various DC Voltage levels which are used to generate the required drives for the DC motors through an electronic control circuit. The overall system configuration is shown in Fig. 1.

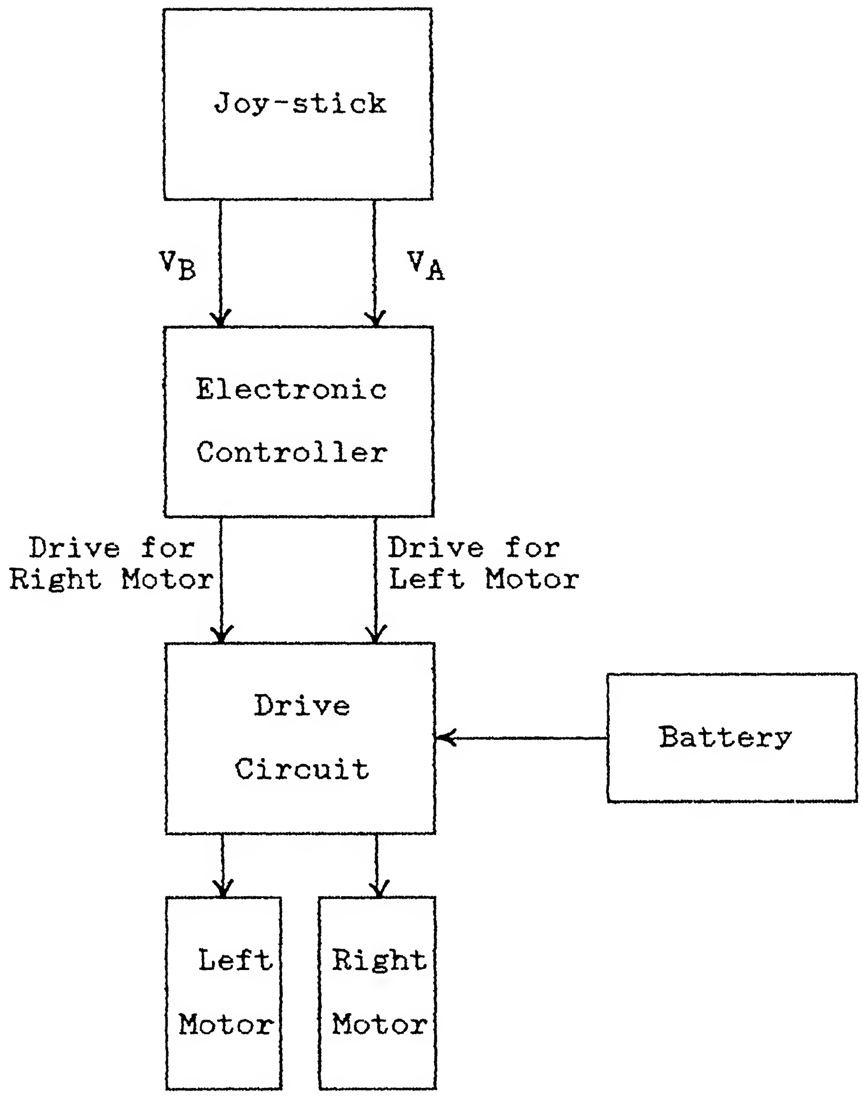


Fig. 1. OVERALL SYSTEM CONFIGURATION

A cable would be passing from the Joy Stick at the operator, to the mobile vehicle. The cable is guided on an overhead reel, however no provision has been provided for reeling and unreeling the loose cable during the motion of the tracked vehicle. Hence, the range of the vehicle is limited to the length of the cable.

With this set up, the operator with repeated use would be able to maneuver the vehicle as far as his line of sight and accuracy could match. The present joy stick control enables the operator, to move the tracked vehicle to a particular position, however due to the inability to move the vehicle sideways the area of operation cannot be precisely achieved.

CHAPTER 2

MECHANICAL HARDWARE DESIGN

2.1 INTRODUCTION

The term "All Terrain Vehicle" is a misnomer. There is no land vehicle in any army's inventory that can climb mountains, jump across ravines, ravel through swampy marshes and perform in all of nature's diverse settings. However, tracked vehicles are found to be 5 : 3 better proposition in rugged and swampy terrain, though not without a real loss in efficiency, because a lot of energy is used to push the mud out of the way, in order to leave the path. The slat band chains as shown in Fig. 2. which form the tracks are driven by DC motors mounted on a fabricated chassis made of aluminum. The left and right tracks are capable of independent traction with a set of Nylon gears.

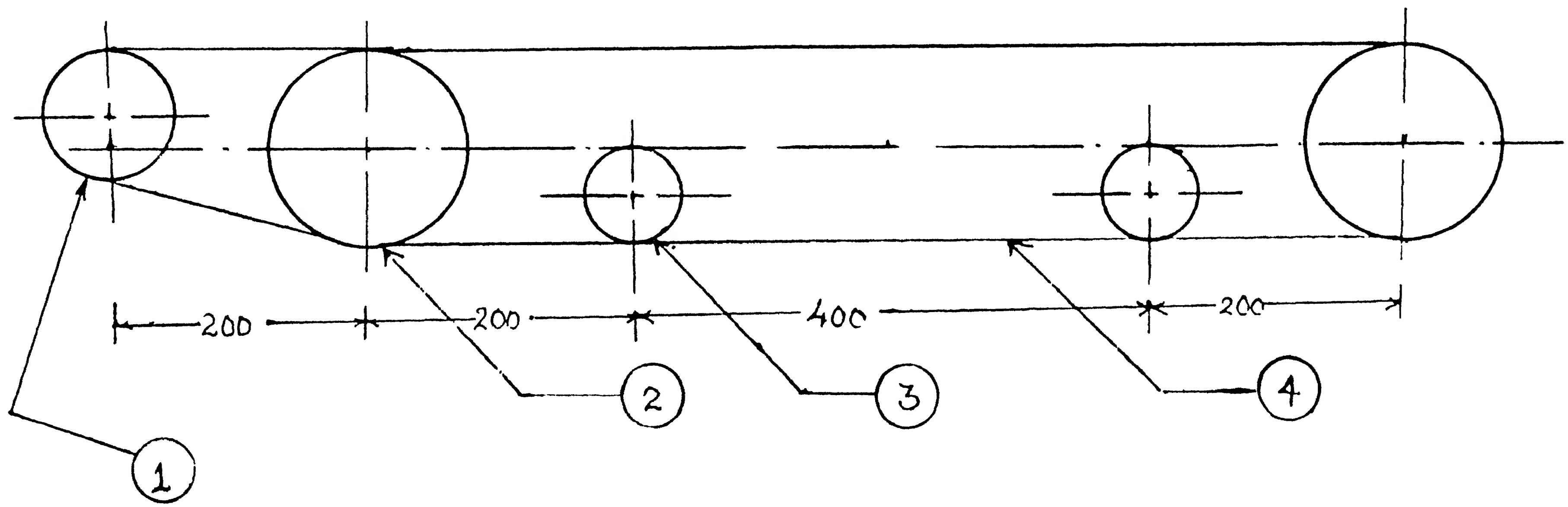
The independent control is obtained by simulating the four quadrant response by joy-stick control. The dry lead-acid battery forms a self contained power pack on the vehicle for driving permanent magnet DC motors.

2.2 DESIGN OF VARIOUS MECHANICAL COMPONENTS AND SUB-ASSEMBLIES

The design and configuration of various sub system are explained in the following section.

2.2.1 TRANSMISSION SYSTEM

The vehicle developed has power transmitted from a set of geared DC motors operating on 24 Volts supply from a pair of 12 Volt dry batteries connected in series. The DC motors are as shown in Fig. 3. Whose specifications are listed at Appendix 1.



All Dimensions in mm.

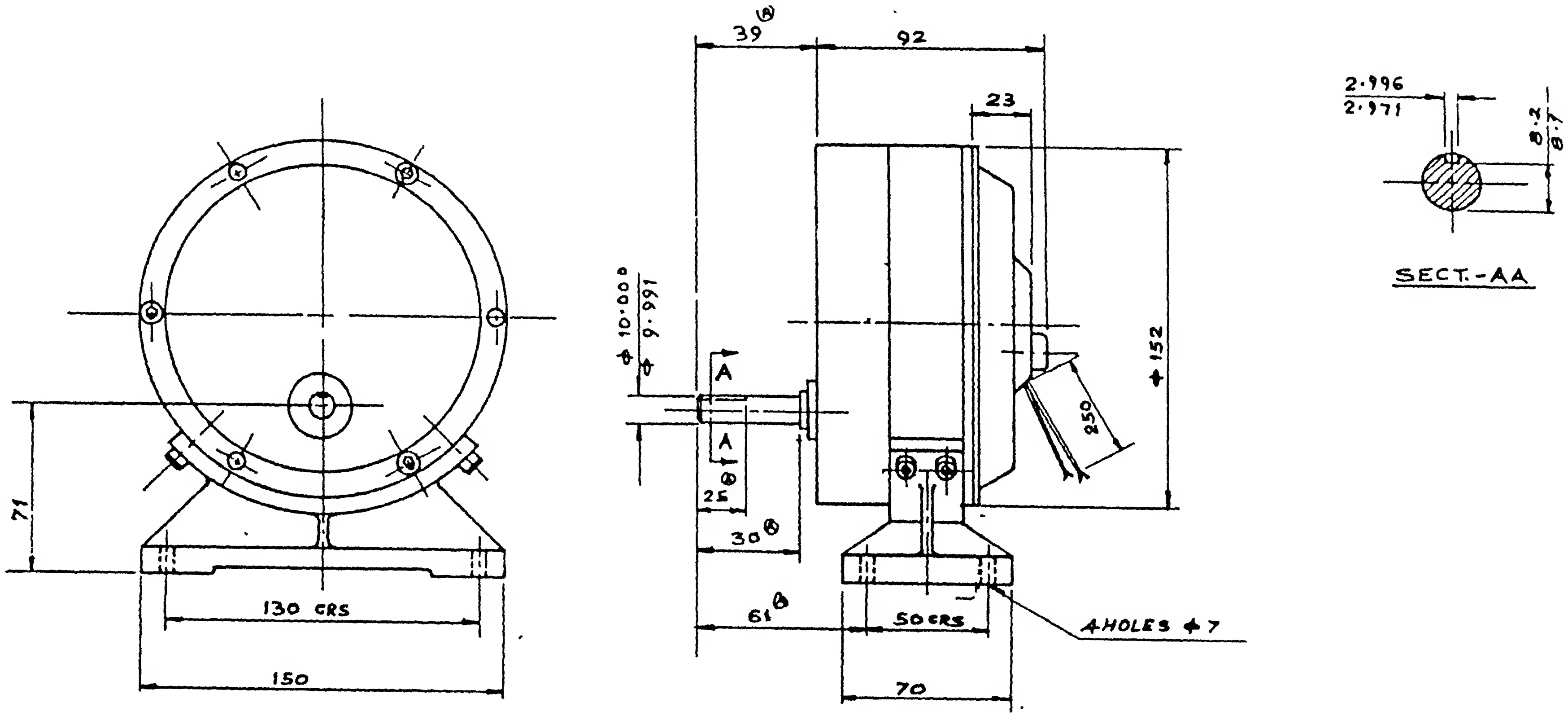
1 Drive Sprocket

2 Driven Sprocket (Idler)

3 Steel Rollers

Slat Band Chains 4

Fig. 2 General Layout of Track Systems



All Dimensions in mm.

Fig. 3 Outline Diagram of Foot Mounted Geared DC Motor

The built in gear reduction of 50 : 1 is obtained by a gear train using spur gears in the motor, accounting for some noise however with an advantage of reduced transmission losses.

2.2.1.1 STARTING TORQUE REQUIREMENTS

The vehicle is acted on by various forces when it is in motion some of which offer resistance to motion [5, 6]. The principal motive force is the tractive forces of the driving sprockets transmitted to the tracks. This force arises out of the motion of the electric motor and depends on interaction between the driving tracks and the terrain. The vehicle is designed with the following constraints:

1) The sum total of unladen and payload not to exceed 100 Kg.

ii) Each track to share the load equally.

iii) Vehicle to negotiate gradients upto 20°.

iv) The maximum linear velocity being limited to 1.5 kph to 2.0 kph. The time required to attain this speed not to exceed 1 Sec. i.e. maximum acceleration limited to 1.5 kph/sec.

The vehicle is subjected to following forces [5].

a) Dragging Resistance (Dr)

What is observed as rolling resistance in wheeled vehicles is synonymous as drag resistance in tracked vehicles. The value of the drag resistance depends upon several factors such as vehicle speed, track pressure, vertical load on the tracks, road surface. Generally accepted expression for wheeled vehicles is

$Dr = W\ (a + b\ V^{n})$

$n = 1$ to 3 ($n = 1$ is common for wheeled vehicles, $n = 2$ is reasonable assumption for tracked vehicles)

v = Velocity in miles per hour

W = Weight of vehicle in pounds

mean values of a and b are

$a = 0.015$

$b = 0.0001$

Hence, in our case

$$Dr = 100 \times 2.2\ [0.015 + 0.0001 \times (1.5/1.6)^2]$$

$$= 3.3 \text{ lbs}$$

$$= 14.7 \text{ Newtons} \qquad \text{(i)}$$

b) Gradient

If a vehicle, moving along a level road at constant speed, starts to climb a gradient at angle 'θ' with level road, energy is required to provide for the change in potential energy. The effect is same as though the vehicle was acted on by a resistance to its motion. The value of resistance is given by

$$Rg = W \sin \theta$$

Hence,

$$Rg = 100 \times 2.2 \sin 20° \text{ lbs}$$

$$= 335 \text{ Newtons} \qquad \text{(ii)}$$

c) Inertia of the vehicle [6]

The power in watts required to overcome the inertia of a vehicle of weight W pounds in a straight line motion is given by

$$p = 0.0907\ W\ V\ dV/dt$$

Where,

V = Speed of vehicle in miles per hour

t = Time in seconds

In case of constant acceleration 'a' the velocity 'V', attained after a time 't' (starting from rest), is given by

$V = at$

Power required to overcome the inertia

$P = 0.0907\ Wa^2t$

$= 0.0907\ WaV_C$

Where V_C = Cruising speed of vehicle

Hence,

$P = 0.0907 \times 100 \times 2{,}2 \times 1.5 \times 1.5 / (1.6 \times 1.6)$

$= 17.5$ watts (I)

2.2.1.2 TOTAL POWER REQUIRED

Total resistance to motion (i) + (ii)

= (14.7 + 335) Newtons

= 350 Newtons

Power in watts = Resistance (N) x Vel. (m/s)

$= 350 \times 1.5 \times 1000 / 3600$

= 146 Watts (II)

Total power in Watts = (I) + (II)

= 17.5 + 146

= 163.5 Watts

This power is assumed to be equally distributed between the two identical left and right drives for the tracks.

Design power considering a load factor of 1.5

$= 163.5 \times 1.5 / 2$

= 122.6 Watts

Torque required at motor shaft at motor speed of 3600 RPM

Torque $= 122.6 \times 4500 \times 100 / (1 \times \pi \times 736)$ Kgcm

= 3.32 Kgcm

On a exhaustive market survey it was possible to obtain a geared DC motor at 24 Volt giving a torque of 2.Ø Kgcm at 36ØØ RPM. This motor was also suitably geared. Allowing for further factor of safety, two identical motors were selected for each track and connected in tandem to give a total torque before reduction of 4.Ø Kgcm.

2.2.2 GEARING AND STEERING SYSTEM

Two motors had to be used for each track to compensate for torque requirements. The motors were positioned with their shafts at 90°, hence a gearing system as shown in Fig 4 is used.

2.2.2.1 GEARING SYSTEM

The permanent magnet DC motors mentioned at 2.2.1 are inbuilt geared motors using precision hobbed gears with a gear ratio of 5Ø : 1. A maximum full load torque of 83 Kgcm at maximum speed of 72 RPM, is available at the motor output shaft. The shaft is coupled by means of a flexible coupling to house a simple differential system as shown in Fig. 4. A 9Ø° change in direction is obtained by using a set of identical cast iron bevel gears having the following specifications.

Blank diameter	47.6 mm
Module	2.Ø mm
Pitch circle diameter	47.3 mm
Width of the blank	12.Ø mm
Thickness at PCD	3.Ø mm
Number of teeth	22
Depth of teeth	2.5 mm

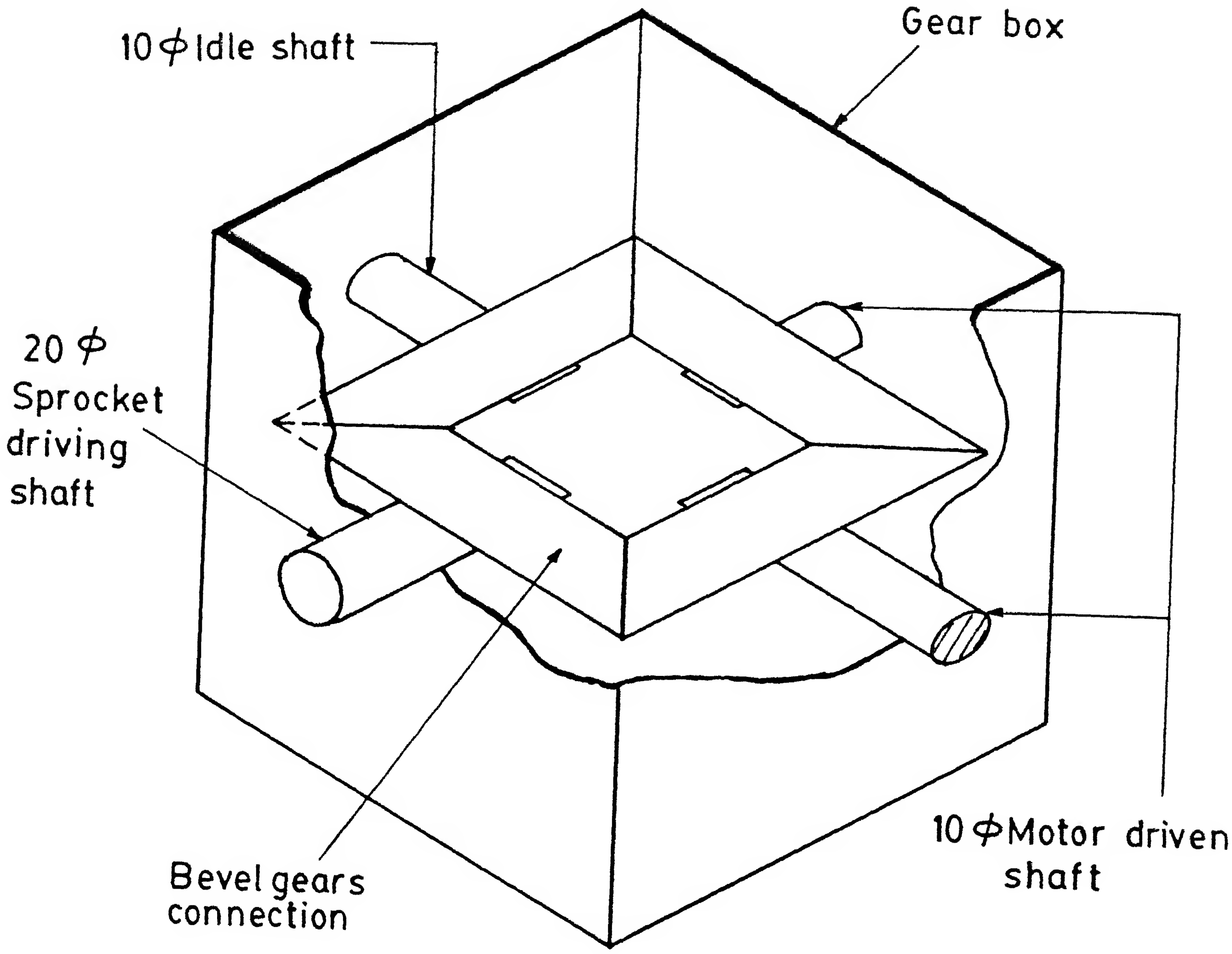


FIG.4 SCHEMATIC VIEW OF GEARING SYSTEM

The two motors are coupled at 90° with appropriate electrical connections at the differential. As each of them assist the other drive, the total torque obtained is the sum total of their individual torques. However it is important that the electrical parameters of the motors should match, to avoid overloading of the motors. The bevel gears are housed in a aluminum fabricated box with ball bearings and mounted on the undercarriage of the chassis.

2.2.2.2 STEERING SYSTEM [7]

The handling characteristics of tracked vehicles have certain unique features as mentioned earlier. A separate treatment of the steering of tracked vehicles is therefore required. There are a number of possible methods that can accomplish the steering of a tracked vehicle. To mention a few :

(1) Skid steering

(2) Steering by articulation

(3) Curved track steering

In articulated steering used in tracked vehicles consisting of two or more units no adjustment of the thrusts of the tracks is required.

In skid steering, the thrust of one track is increased and that of the other is reduced, so as to create a turning moment to overcome the moment of turning resistance due to the skidding of the tracks on the ground and the rotational inertia of the vehicle as shown in Fig. 5. The turning behaviour of a tracked vehicle using skid steering depends on the thrusts of the outside and inside tracks Fo and Fi, resultant resisting force R_{tot},

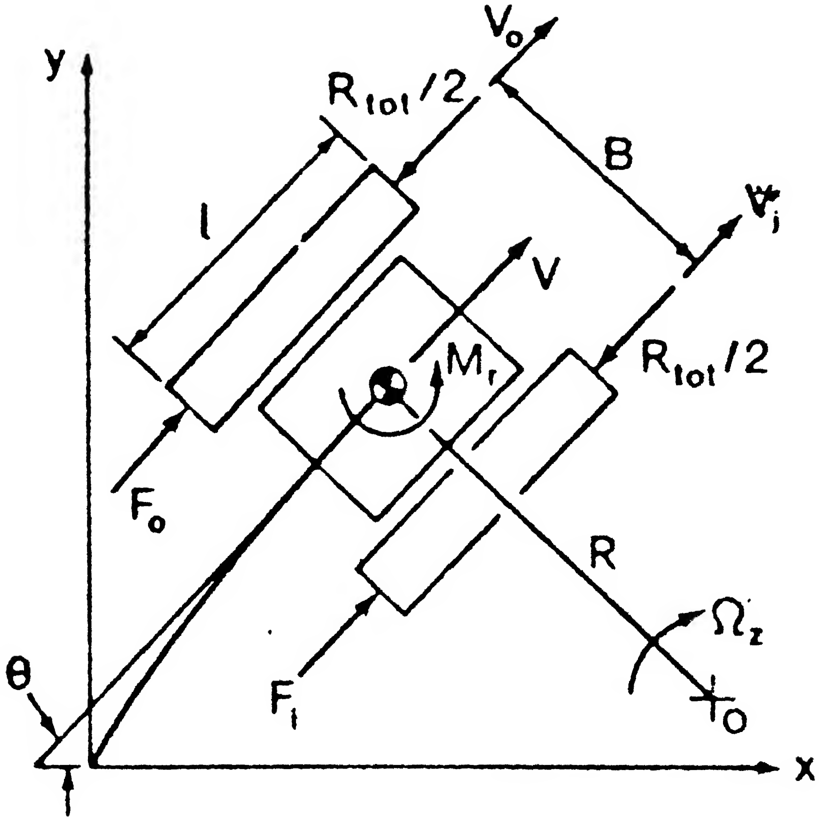


Fig. 5 Principle of Skid Steering

moment of turning resistance Mr exerted on the track by the ground and vehicle parameters are as shown in Fig. 5. At low speeds the centrifugal force may be neglected and the behaviour of the vehicle can be described by the following two equations [8].

$$F_o = \frac{R_{tot}}{2} + \frac{M_r}{B} = \frac{frW}{2} + \frac{M_r}{B}$$

$$F_i = \frac{R_{tot}}{2} - \frac{M_r}{B} = \frac{frW}{2} - \frac{M_r}{B}$$

Where fr, is the coefficient of motion resistance of the vehicle and 'W' is vehicle weight.

As shown in Fig. 5. tracked vehicle is turning about the centre O. When the sprocket of the outside track is rotating at an angular speed of Wo and that of the inside track is rotating at an angular speed of Wi, and the tracks do not slip, the turning radius R and the yaw velocity of vehicle Ω_z, can be expressed by,

$$R = \frac{B}{2}\frac{(rW_o + rW_i)}{(rW_o - rW_i)} = \frac{B\ (Ks + 1)}{2\ (Ks - 1)}$$

$$\Omega_z = \frac{(rW_o - rW_i)}{2R} = \frac{rW_i\ (Ks - 1)}{B}$$

However, during a turning maneuver appropriate thrust or braking force must be applied to the tracks as described previously as a consequence of which the tracks will slip or skid.

2.2.3 TRACK SYSTEM AND CHASSIS / FRAME

Track system which consists of various sub components and fitments have been so selected keeping in view minimization of the dead weight of vehicle. Hence light materials were selected without compromising on strength and rigidity.

2.2.3.1 SPROCKETS AND SLAT BAND CHAIN

With the constraints on the design as brought out in 2.2.1.1 the non metallic sprockets and chains were found to be adequate. However, adequate strength factor has been given consideration. The Nylon and Delrin material have good load bearing capacity.

2.2.3.1.1 DRIVE SPROCKET

The drive from the output shaft of the differential by means of sprocket, drives the slat band chains, as shown in Fig. 2. providing independent drive for the left and right tracks. The stock wheel or the driven sprocket as shown in Fig. 8a. has odd number of teeth of approximately half actual chain pitch. Hence, each tooth engages only once in two revolutions so giving double wear life to the wheel.

The following dimensions are selected for the drive sprocket.

Pitch circle diameter	103 mm
Width of sprocket	42.3 mm
Pitch of teeth	19 mm
Number of teeth	17
Material of sprocket	Nylon

2.2.3.1.2 IDLER SPROCKETS

To provide positive drive over the entire length of chain, idler sprockets are provided as shown in Fig. 8a. The number of this sprockets depend on the length of chain. However alignment problem was faced at the width over the gearing face with the chain, as the number of idler sprockets were increased to more than two.

Two idler sprockets were provided on each side of the track having following dimensions ;

Pitch circle diameter	152 mm
Width of sprocket	42.3 mm
Pitch of teeth	19 mm
Number of teeth	25
Material of sprocket	Nylon

Limitation of the maximum pitch circle diameter available in the market is the cause for the low ground clearance of the vehicle.

2.2.3.1.3 STEEL ROLLERS

To support the free length of the slat band chain between the idler sprockets, steel rollers were used. The steel rollers as shown in Fig. 8**a.** provide contact for the width of the chain, at the chain-terrain inter surface. Two such rollers are provided to support the bottom run of chain on the under side of the slats for each track.

2.2.3.1.4 SLAT BAND CHAINS

The chains provide a level covering platform and incorporate slats in normal materials, made of metallic or non-metallic. There are only two components, the slat and the pin, and the chains engage the wheels by means of hinge gearing barrels. The chains selected are of Delrin material as shown in Fig. 6. having following dimensions.

Pitch of the chain (A)	38.1 mm
Width over slats (B)	76.2 mm
Depth from top of slat to chain centre (C)	6.5 mm
Gearing barrel diameter (D)	13.Ø mm
Width over gearing face (E)	42.3mm
Bearing area	129 mm^2
Working load	25Ø Kgs

2.2.3.2 CHASSIS / FRAME

The drive, idler sprockets and the steel rollers roll over steel pins mounted on cast aluminum brackets as shown in Fig. 8a. The brackets are fixed with help of fasteners on a aluminum U-channel having dimensions of 1ØØ x 4Ø x 12ØØ mm, bend out of a aluminum sheet of 6.25 mm thick. It was intended to go in for extruded channel in the above size. Due to non-availability of the industrial channel locally in the required size, the channel was made by bending the sheet in a hand press. This has led to some amount of twist both longitudinally and laterally even after best of efforts. To give added strength and to prevent twisting between the left and right channels, additional U-channels were provided for reinforcements as shown in Fig. 8b. The frames

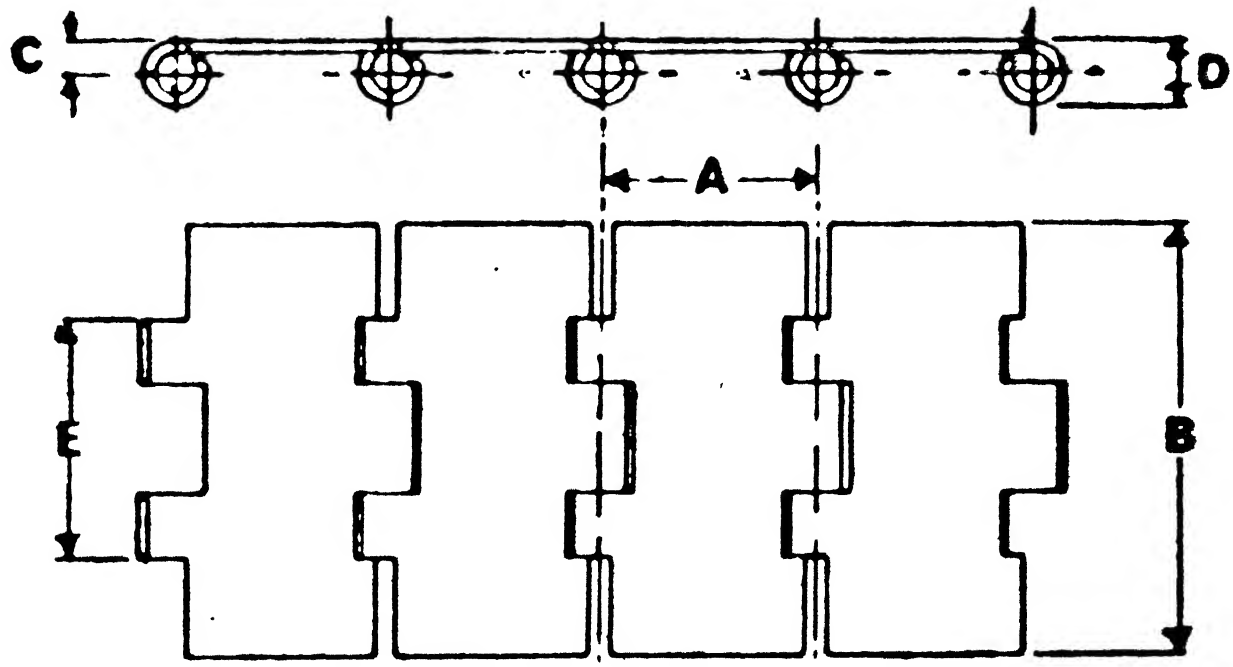


Fig. 6 Segment of Slat Band Chain

also provided mounting platforms for the DC motors, differential gear box and the dry battery.

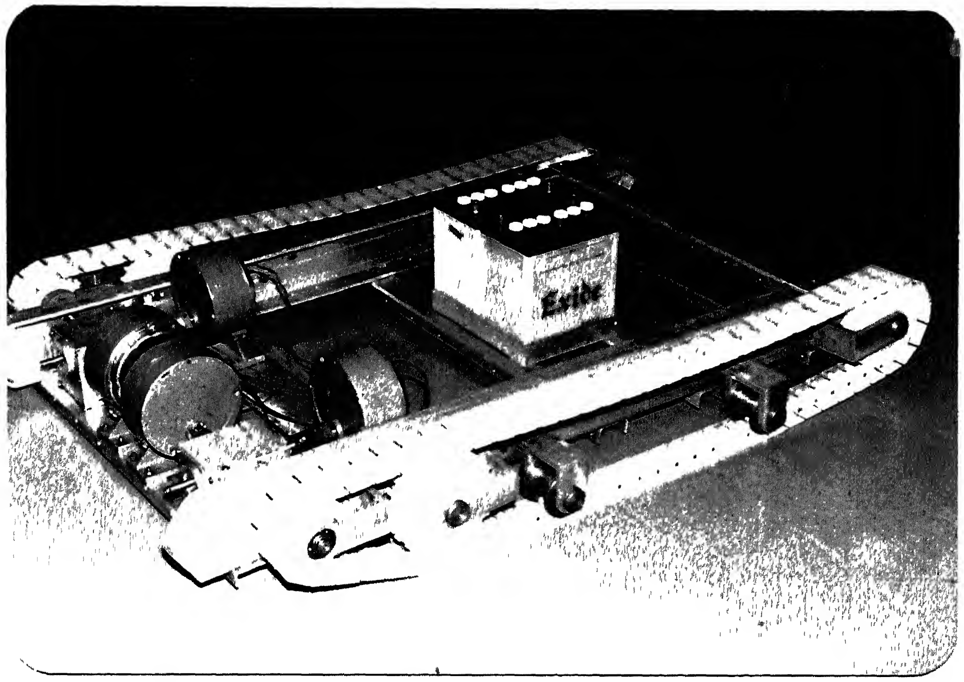


Fig. 8a

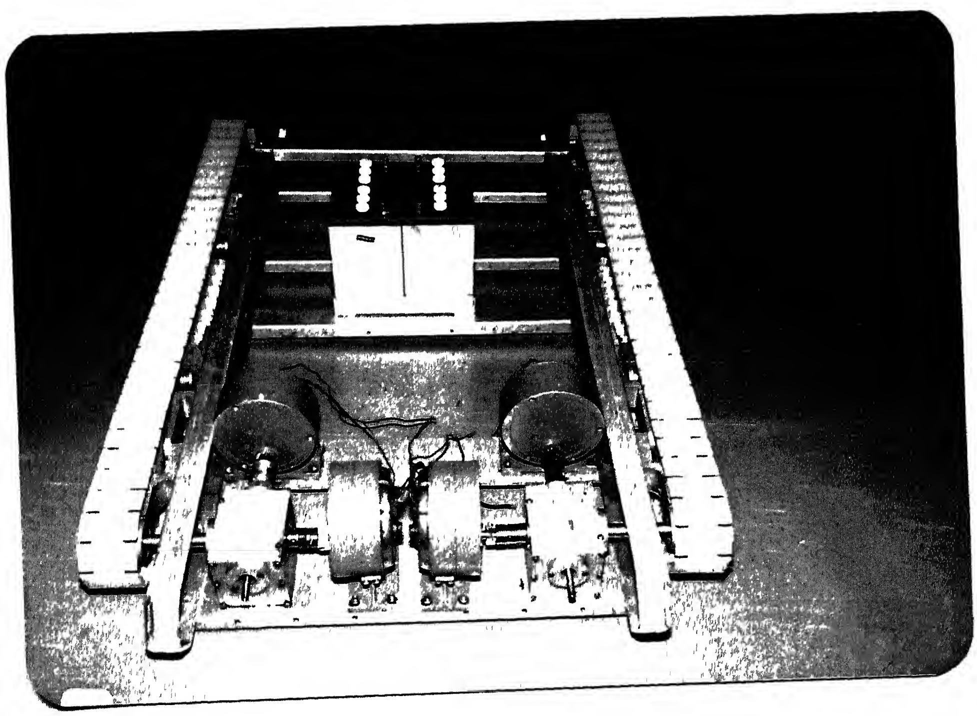


Fig. 8b

Fig. 8 a and 8 b : Tracked Vehicle Assembled

2.3 DESIGN OF JOY-STICK [10, 11]

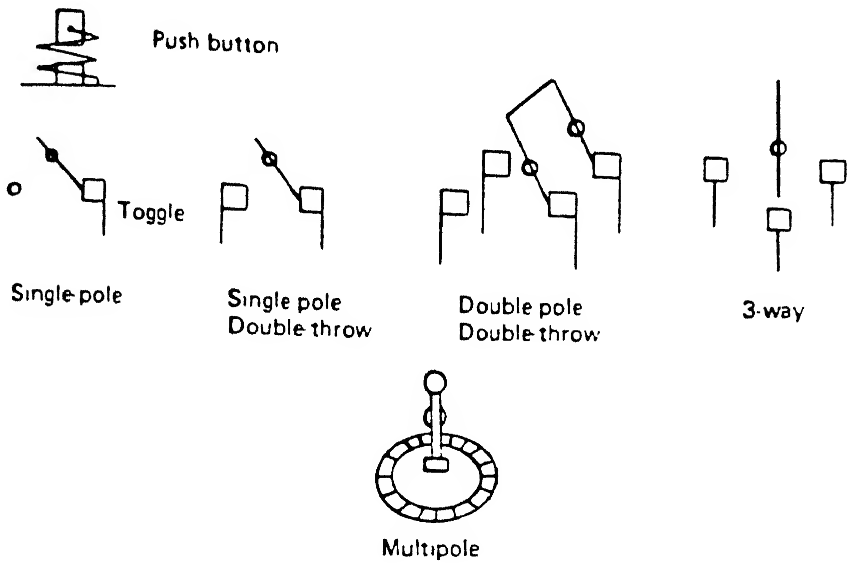
2.3.1 INTRODUCTION

The increased need for remote manipulation in hazardous environments has been widely recognized. Human judgment, skill and sensory interaction are often needed to perform these tasks successfully and safely. A mechanical input device such as a joy stick or a master arm is normally used to control the movements of the mobile vehicle. The state of art of advanced general purpose hand controllers is not well developed.

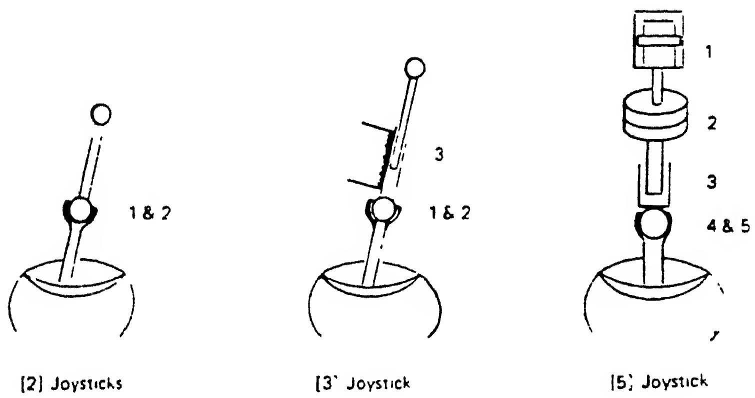
Broadly speaking the man/machine control systems can be divided into two groups (1) simple switches as shown in Fig. 9a. which are on off and (2) the analogue multistep or continuously variable control systems of which the Joy Stick is one form. The various variables for control can be conceived as shown in Fig. 9a. A simple joy stick is frequently used to control two variables as it moves over the surface of hemisphere or smaller fraction of a sphere. A third variable be controlled by making the joy stick telescopic, a fourth by making it sensitive to rotations about its own axis and a fifth by making some kind of pistol grip so that squeezing the palm controls it.

2.3.2 MECHANICAL HARDWARE

The joy stick thought of for the present set up is shown in Fig. 9b and 9c. This is basically a four quadrant joy stick having two degrees of freedom. The X-direction movement is obtained by rotating the entire frame whose axis swivels along the Y-axis. While Y-direction movement is achieved by turning the



Types of Switches



Types of Joysticks

Fig. 9aSimple Switches/Joy-Sticks

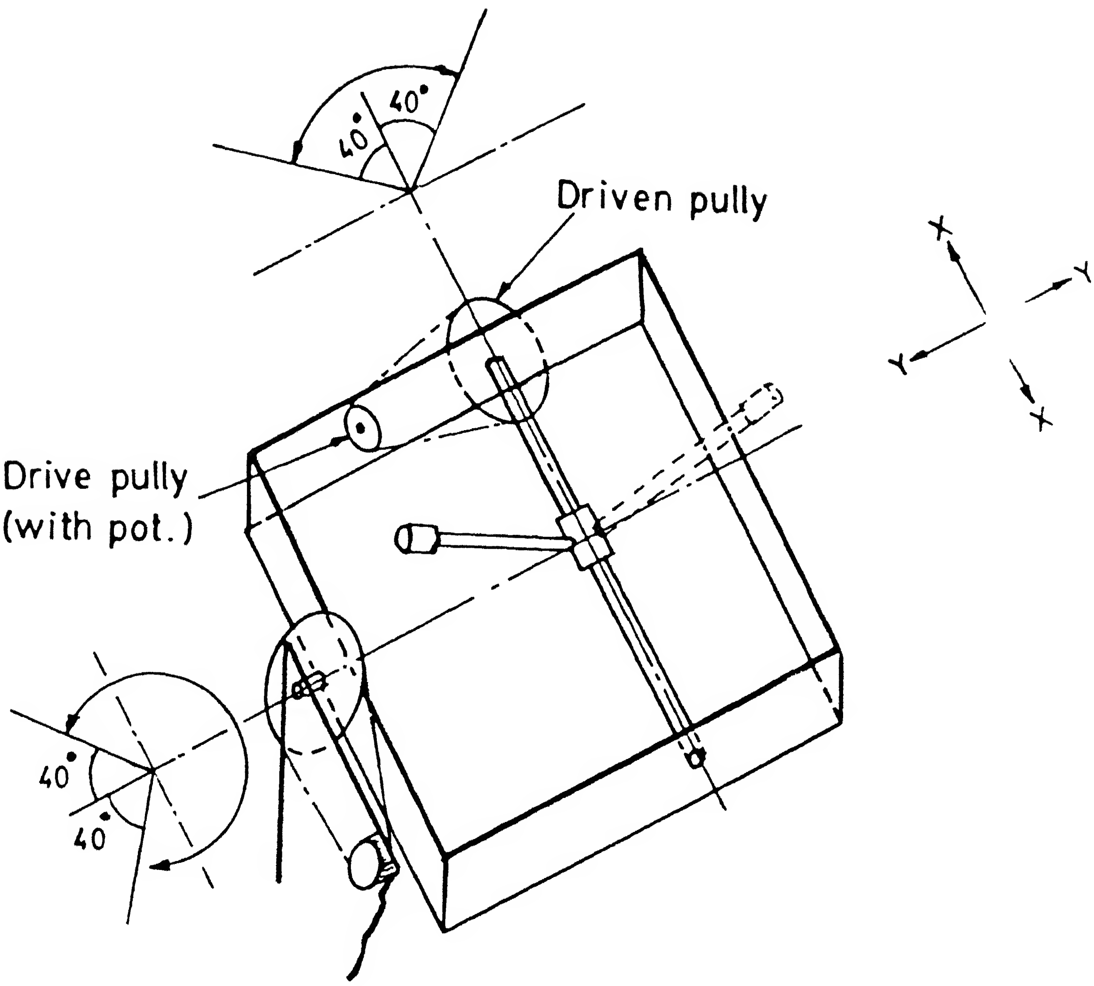


FIG. 9b JOY-STICK CONFIGURATION SCHEMATIC VIEW

shaft forward and reverse, whose axis swivels along the X-axis in the X-Y plane. The drive pulley's are mounted on the swivel axis. The driven pulley's are mounted on a wire wound helical potentiometers, rigidly. Depending on the range of the analogue voltage levels, desired at the varying terminal of the potentiometers, the reduction ratio between the driven and drive pulley's is decided. The entire frame alongwith potentiometers is mounted on a bracket. For ease of machining at the workshop, the entire components were made out of perspex material. The pulley's were driven by flexible 'O' rings as belts.

The potentiometers selected were 5 KΩ, single turn (270°), rated for 3 watts. Allowing a 2.5° dead band at each end of the potentiometer with a reduction of 10 : 3, a 40° angular movement was obtained on either direction. The movement beyond this was restricted by providing stops.

Thus voltage Va and Vb obtained by the movement of the joy stick could vary between -5 to +5 volts.

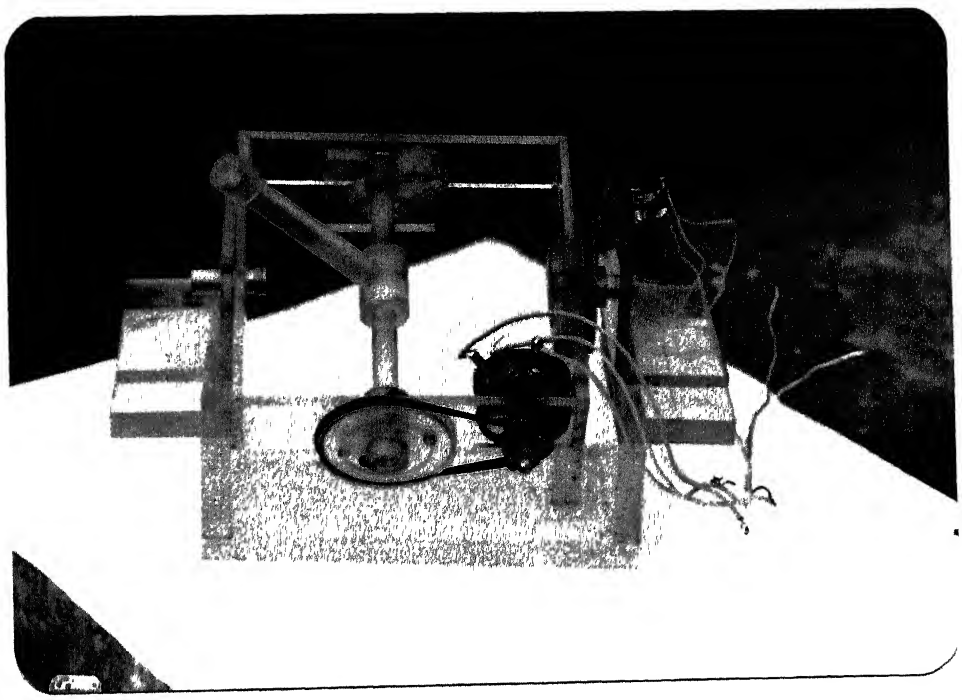


Fig. 9c : Joy_Stick Assembled

CHAPTER 3

ELECTRICAL HARDWARE AND TELEOPERATION

3.1 INTRODUCTION

There are various power drives available which could be used for locomotion of a mobile vehicle. To name than would be :

a) Gasoline engines

b) Pneumatic and hydraulic drive

c) Electric motors

The electric motors for mobile locomotion are being used to advantage due to its high power to weight ratio, less noise better speed regulation an control, and maintenance free operation. However the other forms of energy conversion could be also be used to suit the desired specific requirements, Teleoperation with electrically driven motors can be achieved effectively even we were to realize a simple configuration as shown in Fig. 7. The electronic switches S1 and S2 by merely closing and opening, depending on the duty cycle controlled train of pulses from the teleoperator could govern the speed regulation and direction of a mobile vehicle effectively.

3.2 DESIGN OF VARIOUS ELECTRICAL SYSTEM AND COMPONENTS

Having seen the advantages of using electrical motors as actuators for locomotion of mobile vehicles, various choices are available, namely DC servo motor, brushless DC or AC servomotors, and stepper motors.

1) DC SERVOMOTORS

They provide excellent speed regulation, high torque and high efficiency, and therefore they are ideally suited for

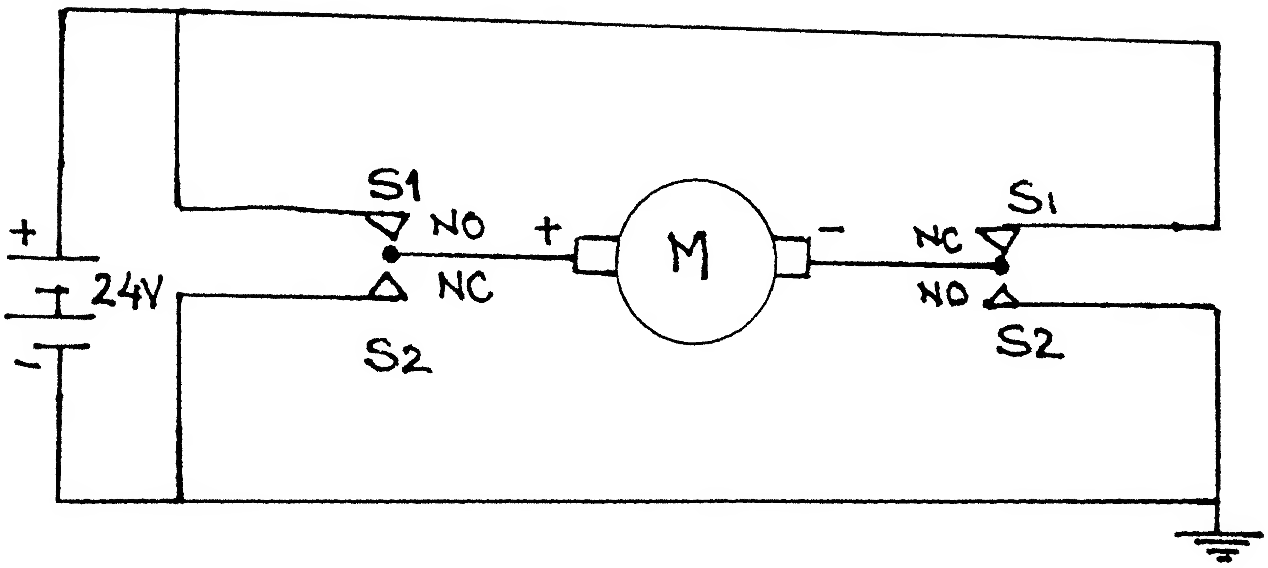


Fig. 7 Simple Switching Configuration

control application. DC motors can be designed to meet a wide range of power requirements and are utilized in most small to medium sized mobile vehicles. A DC servomotor is essentially a transducer of current to torque and allows precise control of speed by manipulation of the voltage.

2) AC SERVOMOTORS

If a permanent magnet DC servomotor is turned inside out so that the magnets form the rotor while the windings are fixed, then no commutator connection to the rotor is needed. Instead the current in the windings must be switched by electronic commutation, or must alternate, in synchronism with the motor rotation.

AC servomotors have several advantages over DC motors,

a) Higher reliability;

b) Low friction;

c) Less electrical noise owing to elimination of the commutator;

d) No sparks hence longer life;

e) High torque to inertia ratio;

f) High torque throughout the speed range;

3) STEPPER MOTORS

They are usually small and of limited torque and speed and tend to be confined to small mobile robots but their power to weight ratio is too poor for manipulation. The attractive feature of stepper motors is that as long as their rated torques is not exceeded their angular position becomes known. As current to each coil is either on or off, simple switching can be used to drive them.

3.2.1 SELECTION OF POWER SOURCE

To have a onboard manipulation or for remote teleoperation it is desirable to have a self contained power source on the mobile vehicle itself. The battery specially constructed for use in on the load electric vehicles is not yet produced by any manufacturer as there is not much demand for the same. Commercial batteries are classified with respect to ampere hour capacity at a given discharge rate. The rates the quotient of capacity over time and has dimension of current. Due to less efficient usage of the active material, discharge time to which battery could be used to a particular discharge rate can be determined only experimentally.

In our requirements the maximum current at any one time would be 20 Amps for driving all the four motors. As the operating voltage of motors is 24 V, two 12 V, dry acid batteries each having a 32 Ampere hour discharge rate were selected. Thus, allowing a reasonable safety margin the vehicle can be conveniently used over a period of 2 to 2.5 hours between two full charging.

3.2.2 SELECTION OF DC MOTOR

As brought out earlier various choices of electrical motors are available. However for our particular application and the torque requirements, DC motors were chosen. As the teleoperation is open loop with human intervention requirement of feed back is not required. Hence, the servomotors and stepper motors are eliminated permitting the use of simple DC motor. For the low voltage and torque requirements of 4 kg-cm, it was

not possible to obtain an indigenous DC motor at this low range. After a exhaustive market survey it was decided to use two permanent magnet DC motors in tandem and accordingly the design was altered.

The Pancake motor as shown in Fig. 3. is a mechanically simplified version of the DC servomotor designed specifically for low cost applications. The flat shape/light weight makes it an ideal package for portable or mobile applications. It is suitable for low voltage or battery powered operation. There is no torque drop off over the full speed range thus, minimizing the motor size requirements. Fast acceleration ensures rapid, accurate response to command signals. The long brush life eliminates maintenance problems. The motor also has an inbuilt gear box using precision hobbed spur gears, with 50 : 1 gear ratio. The motor is foot mounted and dimension are shown in Fig. 3. The electrical motor performance ratings are depicted in Appendix 1.

3.2.3 ELECTRONIC CONTROLLER

As shown in the overall system configuration of Fig. 1, the joy-stick manipulations of the operator are to be converted into pulses of varying duty cycle by the electronic controller whose circuit diagram is given in Fig. 10. The DC level from joy-stick is electronically summed and compared with the help of op-Amps OA_1, OA_2 and OA_3 to generate Va+Vb and Va-Vb. These varying DC levels are compared with positive and negative triangular voltages generated from a function generator. The

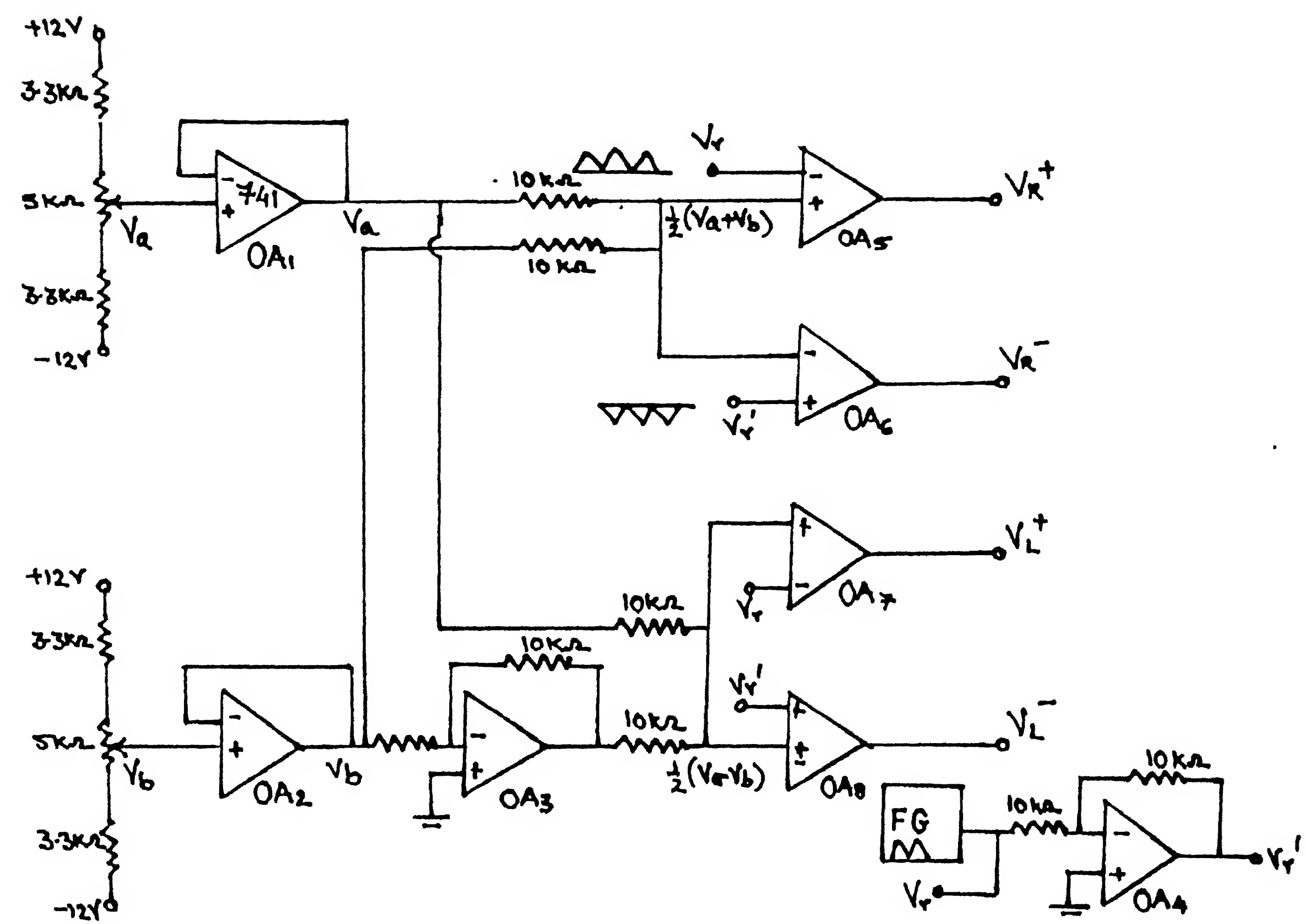


Fig.10 Controller Circuit Diagram

swings of the triangular Voltages Vr and Vr' (= -Vr) being Ø to +5V and Ø to -5V respectively. The op-Amps OA_5, OA_6, OA_7, and OA_8 serve as comparator and generate the outputs V_R^+, V_R^- and V_L^+ and V_L^- which are pulses having swings +12V to -12V with varying duty cycle.

The waveform generated at the output of electronical controller is shown in Fig. 11.

3.2.4 DRIVE CIRCUIT

The drive circuit implements the configuration given earlier in Fig. 7, using four electronic switches SW1, SW2, SW3 and SW4 realized by transistors. The complete circuit diagram is given in Fig. 12. As there are two sets of identical switches SW1/SW2 and SW3/SW4, it would suffice to explain one switch of each type, and we choose SW1 and SW3 for the explanation given below.

The pulsed wave form V_R^+ from the electronic controller having swing from +12V to -12V, is fed to SW1. The RC combination of R11 and C1 and the clipping diode CD1 are used to suppress unwanted spikes in V_R^+ and to clip the negative excursion of V_R^+, which could otherwise lead to the breakdown of the emitter-base junction of the control transistor CT1, whose emitter is grounded. CT1 generates positive pulses at its collector, which are applied to the base of driver transistor DT1. DT1 thus gets saturated when V_R^+ is positive, which in turn causes the power transistor PT1 to conduct and the voltage level at M1 terminal of output reaches +Vcc (SW1 is ON). When V_R^+ is negative, DT1 turns off and hence PT1 does not conduct. Thus the

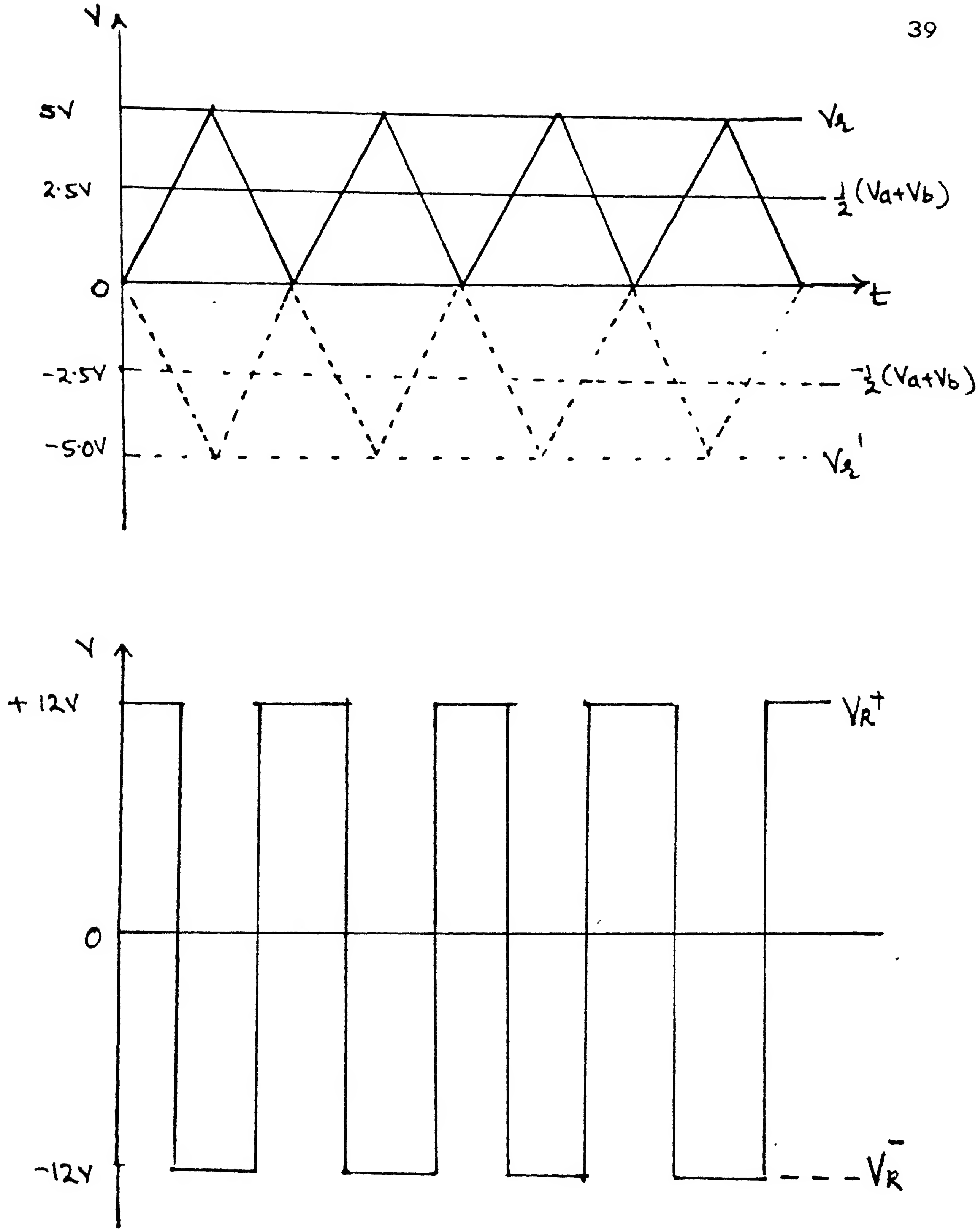


Fig. 11 Output Waveform of Controller

voltage at M1 would be zero, unless forced otherwise. The resistance R13 provides a path for the discharge of the transistor DT1, when it goes from saturation to cutoff. The resistance R14 provides a path for the leakage current of DT1 and also a path for the discharge of the tansistor PT1, when it goes from conduction to cutoff.

At the input of switch SW3, the pulsed waveform V_R^- from controller swings roughly from +Vcc to -Vcc. However, as the negative swing of V_R^- is somewhat above -Vcc, the zener diode is used to provide a level shift so that the transistor switch gets cut off when V_R^- goes negative.

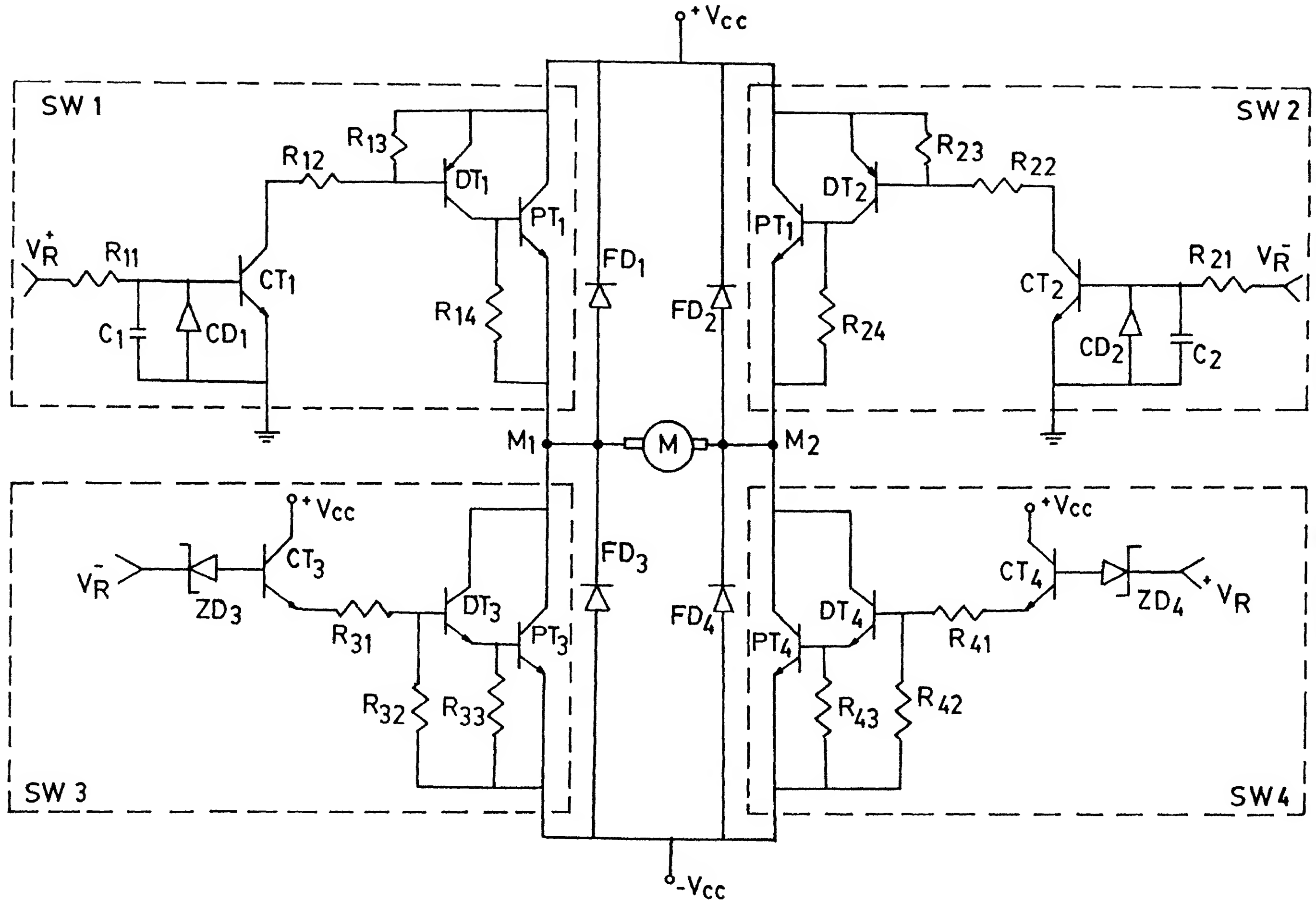
The Control transistor CT3 acts as an emitter follower to pass on the voltage V_R^- shifted slightly down in level. When V_R^- is positive the current through the resistance R31 is sufficient to saturate the driver transistor DT3, which in turn forces base current into the power transistor PT3 and turns it on. Thus -Vcc is available at terminal M1. When V_R^- is negative all the transistors in SW3 are cut off, and the voltage at M1 would be zero unless forced otherwise. The resistance R32 has a role similar to that of R13 in SW1 for the discharge of DT3.

The current to the motors must remain approximately constant, although the voltage between M1 and M2 would be pulsed through the electronic switches. It is therefore necessary to provide alternate paths for the motor current when the transistor swiches are off. This path is provided by the free wheeling diodes FD1, FD2, FD3 and FD4. Thus the driver and the

power transistors are protected from inductive voltage overshoots.

The choice for the selection of various components has been made keeping in view the out put requirements of the DC motor. The motor draws a maximum current of 10 Amps at full load. The base drive required for the collector current of 10 Amps is 0.5 Amps assuming a worst case current gain $\beta = 20$. The drive transistors are therefore required to provide an output current of 0.5 Amps, which is well within the capability of the commonly available SL100 (NPN) and SK100 (PNP) transistors. As these transistors have a minimum value of β around 50, the required out put current of the control transistors would be about 10 mamps. Hence the resistances R12/R22/R31/R41 have been chosen to have value of 1 KΩ. The salient specifications of power transistor used in circuit of Fig. 12. are given below.

VCBO	100 Volts
VCEO	60 Volts
Ic (continous)	15 Amps
Dissipation at 25°C	115 W
Current gain factor at 25°	20 (min) to 70 (max)



SW_1 / SW_2

CD_1 / CD_2 : IN348 B
CT_1 / CT_2 : SL100
DT_1 / DT_2 : SK100
PT_1 / PT_2 : 2N3055
R_{11} / R_{21} : 10K Ω
R_{12} / R_{22} : 1K Ω
R_{13} / R_{23} : 10K Ω
R_{14} / R_{24} : 1K Ω

$C_1 = C_2$: 1000 pf
FD_1 / FD_2 : IN342B

SW_3 / SW_4

ZD_3 / ZD_4 : 3.3V Zener
CT_3 / CT_4 : SL100
DT_3 / DT_4 : SL100
PT_3 / PT_4 : 2N3055
R_{31} / R_{41} : 1K Ω
R_{32} / R_{42} : 10K Ω
R_{33} / R_{43} : 1K Ω
FD_3 / FD_4 : IN342 B

FIG. 12 COMPLETE DRIVE CIRCUIT

CHAPTER 4

RESULTS AND DISCUSSIONS

Any mechanical system having a number of moving elements in variably poses some functional and operational problems. During the course of the design of mechanical hardware much emphasis was on the availability of the items in local market. For example the availability of a low voltage DC motor led to the compulsion of using two DC motors in tandem. This two were available after a exhaustive market survey. There were a very few suppliers who could supply light weight tracks and the sprockets available were also of limited size. The non availability of a large sized sprocket has reduced the ground clearance of the vehicle considerably.

The U-channel on which the entire structure is mounted, due to its non-availability channel locally had to be bent out of aluminum sheet. This has led to misalignment of the two tracks, as the twist in the channel could not be avoided completely. With the available resources the vehicle was fabricated to move on a plane surface. The vehicle was successfully controlled electronically to execute forward and reverse motion.The vehicle was also made to steer to execute left and right turns independently by Joy - stick movement.

CHAPTER 5

SCOPE FOR FURTHER WORK

5.1 INTRODUCTION

The vehicle system developed here, primarily demonstrated a mobile system on tracks. The vehicle system does not fully satisfy the ever growing need for a complete self-contained mobile platform. Amongst the various developmental work that could be done is to develop a more rigid system capable of operating in all weather terrain. The vehicle ideally should have an unlimited range. The vehicle should not depend on the user all the time for inputs. These constraints could be limited to a certain degree.

1. By having a wireless two way communication between the teleoperator and the vehicle.
2. By a vision system which could help the teleoperator to feel the environment and the range at which the vehicle would be operating.

Mobile robots generally have a hierarchial control structure in which onboard software handles the lowest levels such as interrogating sensors and driving motors, and often the intermediate levels such as following a path or even planning a route. The highest level of control is often remote control by a human operator. In this case the on board software must be able to receive commands by radio or some other link and to carry them out maintaining a safe course of action even when communication is interrupted.

5.2 WIRELESS COMMUNICATION FOR TELEOPERATION

The radio link between the mobile robot and base station has to be reliable. Wireless communication could be infra red or by radio. Infra red is strictly a line of sight method and range of operation is limited. The wave generated is in the form of cone and is more prone to obstruction than radio, but is immune to most forms of interference. The signal commands from the teleoperator could be transmitted either with or with out amplitude modulation over a carrier. The modulated signal is demodulated at the receiver in the vehicle to switch on or off the motors.

5.3 THE VISION SYSTEM AND CLOSED LOOP FEEDBACK

The present vehicle uses an user interrupted teleoperation, where the operator has to be in constant view of the vehicle at all times. These limits the range of operation and the accuracy. It is also tiresome when continuous maneuvering of the vehicle is required. This difficulty can be eliminated using a vision system supported with sensors to sense and recognize the surroundings, thus a feedback is available and the operator is able to monitor the vehicle movement.

5.4 USAGE OF PRESENT SET-UP

The present teleoperated tracked system can be used when interfaced with any of the available manipulators as proposed :

a) Mine clearance

b) Mine laying

c) Bomb disposal

d) Transportation of ammunition and other supplies to battle field units

e) Testing for chemical and geological agents and radioactivity

f) Electronic counter measures

g) Reconnaissance and sentry duty

APPENDIX 1

DC MOTOR CHARACTERISTICS

MOTOR PERFORMANCE : RATED

Torque	2.00 Kg-cm
Speed	3600 RPM
Power Output	75.00 Watts
Terminal Voltage	24 Volts
Currents	5.0 Amps

MOTOR CONSTANTS :

Torque Constant	0.518 Kg-cm/Amp
Back EMF Constant	5.3 Volts/1000 RPM
Average Friction Torque	0.20 Kg-cm
Damping Constant	0.060 Kg-cm/1000 RPM
Moment of Inertia	0.0016 $Kg\text{-}cm^2$
Terminal Resistance	1.00 Ohms
Mechanical Time Constant	0.038 MSec

GEAR DATA :

Gear Ratio	50 : 1
Speed	72 RPM
Torque	83 Kg-cm
Weight of Motor	2.73 Kg

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